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(54) APPARATUS FOR PRODUCING FIBERS FOR OPTICAL TRANSMISSION

(71) We, SUMITOMO ELECTRIC INDUSTRIES, LTD., a Japanese company of No. 15, Kitahama 5-chome, Higashi-ku, Osaka-shi, Osaka, Japan, do hereby declare the invention for which we pray that a patent may be granted to us and the method by which it is to be performed to be particularly described in and by the following statement:

This invention relates to an apparatus for manufacturing fibers for use in optical communication.

Methods for manufacturing fibers for use in optical communication (the fibers of this type will be referred to simply as optical fibers or fibers, hereinafter) from a preformed or raw material are classified into two types, i.e. a preforming method and a double-crucible method. The present invention is associated with the former preforming method, according to which a preformed raw material for fibers is delivered at a given speed into a furnace to heat and soften the same, and then a fiber is drawn therefrom. This method is referred to as a fiber drawing method. One of the requirements in this method is uniformity in high mechanical strength and in the outer diameter of the obtained fiber along its length. The strength of fibers is essential to sustain subsequent cabling processes, and cable installation processes. Particularly, uniformity in the outer diameter of fibers is extremely important to improve characteristics for fiber splicing and connecting.

In practice it is most important to be able to reproduce an optical fiber having a uniform outer diameter consistently. Variations in the outer diameter of the fiber cause variations in the core diameter, which in turn causes conversion of the transmission mode and deterioration of transmission characteristics. Further, in this field careful attention should be paid to fiber splicing and connecting. In order to obtain a substantially perfect fiber splicing or connection, light is usually projected into a fiber from one end thereof and is received at the other end of the other fiber. The relative positions of the fibers are adjusted until a maximum level of light is received. However, such work takes considerable time, particularly when installing the optical fiber cable in a manhole or an underground passage. Recently fibers have been connected using a melt bonding connection or a V-shaped groove is used to fix the fibers relative to each other, standardizing the outer diameter of the optical fibers. In this case, it is necessary to prepare fibers having substantially the same outer diameter.

In a drawing operation as shown in Figure 1 a preformed material 1 having an outer diameter D is fed into a draw-forming furnace 2 at a speed V. In the furnace 2, a neck-down region 3 of the fiber exists and a fiber 4 is drawn therefrom at a speed v. A fiber-diameter measuring system 5 is provided downstream of the furnace 2. Assuming that there is no variation in specific gravity due to the evaporation of raw material at the time of heating and due to the drawing of the fiber, then the following equation may be established under normal conditions:

$$D^2V = d^2v \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

wherein d is the outer diameter of the fibre.

According to the draw-forming step of the preforming method, no jig, such as a die, for the neck-down step of the fiber is used as shown in Figure 1. From equation 1, the outer diameter d of a fiber derived is given by:

$$d = D\sqrt{\frac{V}{v}} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

A further important factor to be considered in fiber formation is the disadvantageous variation in diameter of a fiber along its length due to variations in the viscosity of the fiber in the neck-down region and also in the temperature for heating and softening the preformed material.

Variations in the diameter of fibers can be placed into two categories, i.e., a short term variation and a long term variation. The short term variation occurs in the range of several centimeters to one meter, while the long term variation occurs at more than one meter. The long term variation may be corrected with relative ease by adopting an automatic control system for controlling the fiber diameter. However, in the drawing process, a variation in the diameter of a fiber is detected after a dead time during which the variation in diameter has taken place. Such an unwanted lapse of time is apparently caused by the position of the fiber-diameter-measuring system 5 as shown in Figure 1. In the control system with such a dead time there exists a minimum possible period which may theoretically be controlled. Accordingly, a variation for a relatively short period fails to be improved by the automatic control system for fiber diameter, and therefore it is necessary to eliminate the factor which causes these disadvantageous relatively small term variations.

An additional concern in the fiber drawing operation is the material of the heating means which affects the outer diameter of the fibers and the mechanical strength thereof.

Carbon serving as a heat generating element is typically manufactured by molding a material consisting of, for example, petroleum cokes, pitch cokes or carbon black, followed by baking at a temperature of 1000° to 1300°C. On the other hand, graphite is made of the same raw material as that for carbon by being molded into a desired shape, followed by baking at a temperature of 1000° - 1300°C, and then further heating at a temperature of 2500° to 3000°C for graphitization.

If carbon and graphite are used for heat generating elements in the draw-forming furnace, a binder contained therein is evaporated due to the heating encountered during its service, so that carbon powder forming the carbon or graphite heating element becomes exposed. Under this condition, the carbon powder floats or flies within the furnace, thus impairing the atmosphere in the furnace. The adverse influences exerted by the carbon powder are enumerated as below:

First carbon powder is brought into contact with the heated preformed material for reaction with constituents contained therein. For instance, carbon powder reacts with SiO_2 in the preformed material, as follows:

$$SiO_2 + C \longrightarrow SiC + O_2$$

In this matter, part of the surface of the preformed material is formed of silicon carbide. As a result, a foreign material is formed so that the strength of such a portion of the fiber is lowered, accompanied by a variation in diameter of the fiber in such portion. If a quartz rod with carbon powders adhering to the surface thereof is drawn at a temperature of about 2000°C, the obtained fiber becomes extremely fragile or brittle, so that such fiber will not survive in actual use.

Second, if carbon powder clings to such a portion of the fiber, there results a wider variation in the apparent outer diameter of the fiber when the temperature is lowered.

This exerts an adverse influence on the automatic control of the diameter of the fiber. Further, plastic cladding fiber, one example of a fiber for optical communication, is produced by setting a pure quartz or optical glass rod into the draw forming furnace to obtain a core having a predetermined core diameter, and immediately thereafter a plastic material having a lower refractive index than that of the core is coated thereon to form a cladding. If the atmosphere in the drawing furnace is contaminated, the core surface will be polluted, so that the characteristic of the fiber is degraded. Particularly, transmission loss is increased. In the case where pure quartz or quartz glass is used, the draw-forming temperature should be extremely high, about 2000°C as shown in Figure 2 so that such a high temperature would affect the atmosphere within the furnace. For example, carbon powders floating in the furnace easily react with a silica as mentioned above in the quartz or optical glass to produce silicon carbide at the core surface at the high temperature of 2000°C.

The mechanical strength of the optical fiber is also important in order to avoid snapping

of the fiber in the manufacturing process to enhance yieldability. Further it is advantageous in designing and producing the optical fiber if the high mechanical strength of the fiber is maintained. Furthermore, the obtained optical fiber will be compact because there will be no need for reinforcing the fiber, which enhances communication capacity per unit area of the fiber cable. Therefore, a fiber having high mechanical strength has been badly needed.

It is therefore, an object of the present invention to obviate or mitigate the above-mentioned drawbacks and disadvantages.

According to the present invention, there is provided an apparatus for draw-forming optical fibers, comprising an oven for receiving a preformed raw material and containing, in use, an inert gas, and heating means within said oven for heating said raw material to a temperature suitable for drawing, said oven having a substantially cylindrical interior surface with no discontinuous or stepped portions so that turbulence of inert gas, in use, within said oven is minimized, thus minimizing fiber diameter variations due to temperature variations caused by said turbulence, said interior surface comprising a pyrolitic graphite, glassy carbon or other carbonaceous material which releases little or no carbon powder when heated to said suitable temperature.

In the accompanying drawings:-

Figure 1 is a schematic view showing the essential elements in a fiber drawing operation;

Figure 2 is a graph showing the relationship between the draw-forming temperature and the axial position in the furnace with the zero point being defined only as the axial position within the furnace at which the temperature is at maximum;

Figure 3 is an axial sectional view of a high frequency induction heating apparatus according to the first embodiment of the present invention;

Figure 4 is a graph showing the relationship between the temperature within the furnace and the outer diameter of the fiber;

Figure 5 is an axial sectional view of a high frequency induction heating apparatus according to a second embodiment of the present invention;

Figure 6 is an axial sectional view of a high frequency induction heating apparatus according to a third embodiment of the present invention;

Figure 7 is an axial sectional view of a high frequency induction heating apparatus according to a fourth embodiment of the present invention;

Figure 8 is an axial sectional view of a resistance heating apparatus according to a fifth embodiment of the present invention;

Figure 9 is an axial sectional view of a resistance heating apparatus according to a sixth embodiment of the present invention;

Figure 10 is a graph showing the variation of the outer diameter of the fiber formed by an apparatus according to the present invention;

Figure 11 is a graph showing the relationship between applied wave length and the transmission loss of a plastics cladded fiber in whose production an apparatus according to the present invention was used;

Figure 12 is a second graph showing the relationship between the applied wave length and the transmission loss of a plastics cladded fiber in whose production an apparatus according to the present invention was used;

Figure 13 is a graph showing the fiber strength of a conventional fiber; and

Figure 14 is a graph showing the fiber strength of a fiber in whose production an apparatus according to the present invention was used.

Examples of suitable methods of heating for use in draw-forming a fiber are high frequency induction heating, resistance heating, oxyhydrogen flame heating, CO_2 laser heating, and plasma flame heating. According to a preferred embodiment of the present invention, however, high frequency induction heating and resistance heating using carbon or graphite heating elements are employed.

A carbon element is generally used as a heat generating element for use in a fiber-drawing furnace. For this reason, the furnace is filled with an inert gas such as Ar or N_2 to prevent oxidation and hence consumption, of carbon in the furnace, maintaining the internal pressure in the furnace at a positive pressure level. Various experiments by the inventors have shown that, if there is a discontinuous portion or stepped portion in the inner wall of the furnace, it is impossible to reduce the short term diameter variations within $\pm$ 3μm. On the other hand, the experiments show that if the furnace is constructed having an inner wall free of discontinuities but generally cylindrical as shown in the first embodiment illustrated in Figure 3, the diameter variations may be reduced to $\pm$ 0.5 μm. Although Figure 3 shows a high frequency induction heating furnace according to a first embodiment of the present invention, the same results can be obtained by means of a resistance furnace.

In Figure 3, 6 is a top lid for the furnace, 7 a lower lid, 8 a fixing or clamping metal piece, 9 an O-ring, 10 a quartz tube, 11 a heat insulating material, 12 a carbon heat-generating

element, 13 an induction coil, and 14 an inlet for an inert gas.

The innermost peripheral wall of the furnace, namely the heat-generating element 12 is linear in axial section, and has a circular cross-section. Thus it is cylindrical with no surface discontinuities or stepped portions. The reason for the reduction of small periodic variations by forming the inner wall of the furnace with no stepped portion is as follows:-

Despite the fact that an ordinary thermal phenomenon requires a considerably long time constant, a quick response may be achieved in the draw-forming process because the thermal transmission mechanism is radiation and the thermal capacity of the neck-down region is extremely small. This is well substantiated by tests in which the temperature of the furnace is varied quickly or sharply (for instance, the output of a high frequency oscillator is varied), and a response in the diameter of fibers results instanteneously, i.e., the diameter of the fibers is increased very quickly as shown in Figure 4.

As is apparent from the foregoing, according to the present invention there is no discontinous or stepped portion in the inner wall of the furnace and, thus, there is no danger of inert gas streams causing a turbulence. Since the draw-formation is carried out by using a heat-generating element which is free of a discontinuous portion, variations in temperature which would otherwise have been caused due to turbulence of the gas streams is minimized. As a result, variations in the diameters of fibers derived according to the process of the present invention may be reduced to below ± 0.5 μm.

A second embodiment according to the present invention is shown in Figure 5, wherein a high frequency induction heating apparatus is illustrated. A heater 15 made of carbon or graphite has a large wall-thickness at an intermediate portion thereof in order to reduce its impedance. Shown at 16 is a heat-insulating material, at 17 a spacer, at 18 an entrance for inert gas, at 19 furnace pipe made of quartz, and at 20 an induction coil.

According to this embodiment, an ordinary type carbon or graphite is used as a raw material for the heater 15, but a coating 15*a* of pyrolitic carbon made by Nippon Carbon K.K., under the product name PYROLYTIC GRAPHITE, or made by Tokai Carbon K.K. under the product name TOPCOAT, is coated over a part or the entire inner peripheral surface of the heater 15. This pyrolytic graphite is laminated on the surface of the raw material according to a CVD (Chemical Vapor Decomposition) method well known in the art, and the layers thus prepared exhibit a high density and high purity.

In manufacturing glassy carbons, a Furan resin raw material is placed in a mold and gradually heated in an oven until it decomposes. Since the carbonization rate of the material reaches 60 - 70%, the material contracts significantly so that a homogeneous high-density carbon results. Thus, glassy carbon will give off much less carbon dust than conventional carbon or graphite which has a relatively porous structure. Pyrolitic graphite is formed by introducing a hydrocarbon such as propane as an additional raw material into the heated base material. The gas is thermally decomposed according to a known Chemical Vapor Decomposition (CVD) process and a laminated high-density layer is formed on the base material.

The oxidation of these special carbons merely produces CO and CO_2 gases, with little or no production of detached carbon powder as is experienced with conventional carbon heating elements. As a result, the atmosphere in the furnace is improved to a large extent. Of course, the variation of the diameter of fibers due to the turbulence of inert gas streams is prevented by forming a cylindrical inner peripheral surface having no discontinuities.

A third embodiment in accordance with the present invention is shown in Figure 6, wherein a refractory tube 22 made of carbon or graphite is coated on its inner surface with pyrolitic carbon 22*a* having a thickness of less than 4 mm. In this embodiment, the interior of the furnace is covered with the pyrolitic carbon and is substantially cylindrical avoiding stepped wall portions and, therefore, pure and clean atmosphere results and a fiber having a uniform outer diameter along its length is obtained. Of course, the wall thickness of the central portion of the heater is large as in the second embodiment, the principal difference being that the tube is not heated indirectly by the heating means rather than comprising an integral part of the heater as in Figure 5.

A fourth embodiment in accordance with the present invention is shown in Figure 7 wherein reference numeral 29 designates a refractory tube made of glassy carbon. The remaining structure is similar to the device of Figure 5. With this structure, since the refractory tube 29 is made of glassy carbon, and since the glassy carbon itself does not create carbon particles due to its wearing, a clean atmosphere in the furnace results. Furthermore, disadvantageous carbon powders generated from the heater 15 are blocked by the refractory tube 29, and therefore, carbon powders do not float within the tube 29. Of course, the inner wall of the drawing furnace is cylindrical having no discontinuous or stepped portions, so that a stable flow of the inert gas is provided, which in turn reduces the above-mentioned short period variation of the fiber.

A fifth embodiment according to the present invention is shown in Figure 8, wherein a

resistance heating furnace is shown as opposed to the first four embodiments wherein high frequency induction heatings are shown. The fifth embodiment is substantially similar to the embodiment illustrated in Figure 5, except that heat is applied by an electrical resistance heater 35 made of carbon or graphite connected to electrodes 38, 38. Reference numeral 36 designates a refractory tube make of carbon, 37 a heat insulator, 39 spacer to support the heater 35, 40 an inert gas inlet for preventing the heater 35 and the refractory tube from wearing due to oxidation, and 41 the outer wall of the furnace. Water may be introduced into the wall 41 for cooling purposes. In this embodiment, the refractory tube 36 made of carbon and graphite is coated with a pyrolitic carbon coating 36*a* having a thickness of less than 4 mm on part or all of the inner peripheral surface thereof. The same effect and function is obtained in this embodiment as obtained from the foregoing embodiments. However, it should be noted that in order to avoid a short circuit between the electrical resistance heater 35 and the tube 36, a clearance is required therebetween and preferably, the tube 36 should be insulated from the other elements.

A sixth embodiment according to the present invention is shown in Figure 9, wherein a resistance heating furnace is shown. In this embodiment, the carbon tube 42 is made of glassy-carbon. This embodiment is substantially similar to the embodiment of Figure 6 with the exception of the resistance heater, and the same function and effect is obtained as in the foregoing embodiments.

Figure 10 shows the variation of the outer diameter of the fiber obtained by the apparatus shown in Figure 9. In Figure 10, owing to the automatic control system for fiber diameter, long periodic variation is completely eliminated and, furthermore, the amplitude of the short term diameter variation is reduced to ± 0.3 μm.

In Figures 11 and 12, the transmission loss characteristics of the plastics cladded fibers is shown, in which quartz and a silicone resin are used as the core material and cladding material, respectively, and the drawing furnace according to Figure 6 is employed.

The core diameter is 150 μm and the clad diameter is 350 μm, the cladding having a refractive idex 4.0% lower than that of the core. In the test piece used in connection with Figure 11, a quartz rod made by Komatsu Denshi Kinzoku K.K., under the product name Silanox-WF, is used as the core and a silicone resin made by Shinetsu Kogaku K.K., under the product name KE-103RTV, is used as a cladding material. In the test piece used in connection with Figure 12, a synthetic quartz rod obtained by using high frequency plasma heating is used as a core, and the same material as above is used as the cladding material.

According to Figure 11, at the wave length of 0.83 μm, a low transmission loss of 3.7 dB/km is obtained, and according to Figure 12, at the wave length of 1.05 μm a low transmission loss of 2.4 dB/km is obtained.

These values can be considered a minor transmission loss due largely to the intrinsic loss of the quartz glass core and the intrinsic loss of the clad material. The above tests and considerations prove that the atmosphere in draw forming furnace according to the present invention is extremely clean.

Figure 13 shows Weibull probability plots of the strength of the fiber obtained by the conventional fiber drawing furnace. The conventional furnace was obtained by removing the glassy carbon-refractory tube from the embodiment shown in Figure 7, and, therefore, the atmosphere in the conventional furnace is extremely contaminated. The plastic coated fiber is obtained by the method described in British Patent No. 1,466,224, in which the primary coating is effected immediately after fibre-draw formation, and thereafter, a polyethylene is coated thereon.

Figure 14 shows Weibull probability plots for fiber strength obtained by the instant furnace as shown in Figure 6, and the optical fiber is obtained by the method as above. The fibre thus obtained has an outer fiber diameter of 150 μm, an outer diameter of the polyethylene coating of 0.9 mm, and the tensile strength test was made by using such a fiber having a length of 1 m and a tensile rate set at 5 mm/min.

As is clear from the two graphs, the optical fiber obtained by the instant furnace exhibits remarkably high tensile strength up to 7 kg, and no sample exhibits fracture at less than 7 kg according to tensile strength test.

In view of the foregoing, the outer diameter variation of the fiber produced by using the draw forming furnace according to the present invention is reduced to less than ±0.5 μm, and an optical fiber having high tensile strength of 7 kg is obtainable. Further, the furnace of this invention can provide a remarkably clear atmosphere, since the transmission loss of the plastics cladded fiber is in the range of 2.4 - 3.7 dB/km and this value is almost equal to the intrinsic transmission loss of the quartz.

WHAT WE CLAIM IS:-

1. An apparatus for draw-forming optical fibers, comprising an oven for receiving a preformed raw material and containing, in use, an inert gas, and heating means within said oven for heating said raw material to a temperature suitable for drawing, said oven having a

substantially cylindrical interior surface with no discontinuous or stepped portions so that turbulence of inert gas, in use, within said oven is minimized, thus minimizing fiber diameter variations due to temperature variations caused by said turbulence, said interior surface comprising a pyrolitic graphite, glassy carbon or other carbonaceous material which releases little or no carbon powder when heated to said suitable temperature.

2. An apparatus according to claim 1, wherein said internal surface of said oven is defined by a refractory tube of said pyrolitic graphite, said glassy carbon or said other carbonaceous material.

3. An apparatus according to claim 1 or 2, wherein said heating means comprises a carbon or graphite tube having on the interior surface thereof a coating of said pyrolitic graphite, said glassy carbon or said other carbonaceous material.

4. An apparatus according to claim 3, wherein said coating is less than 4 mm thick.

5. An apparatus according to claim 1, wherein said heating means comprises a resistance heater.

6. An apparatus according to claim 1, wherein said heating means comprises a high-frequency induction heater.

7. An apparatus for draw-forming optical fibers substantially as hereinbefore described with reference to Figure 3, or Figure 5, or Figure 6, or Figure 7, or Figure 8, or Figure 9 of the accompanying drawings.

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ATV Centre,
Birmingham B1 1TT.
Agents for the Applicants.

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Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

FIG. 1

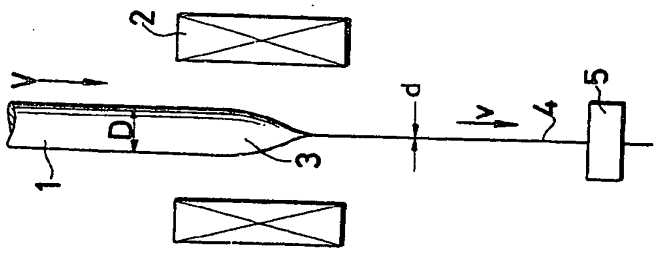

V
D
d
v
1
2
3
4
5

FIG. 2

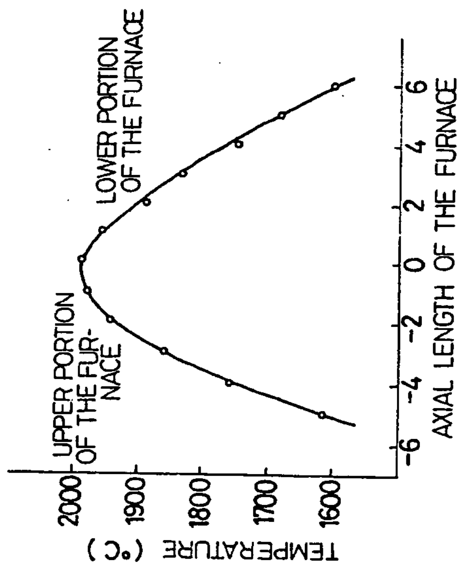
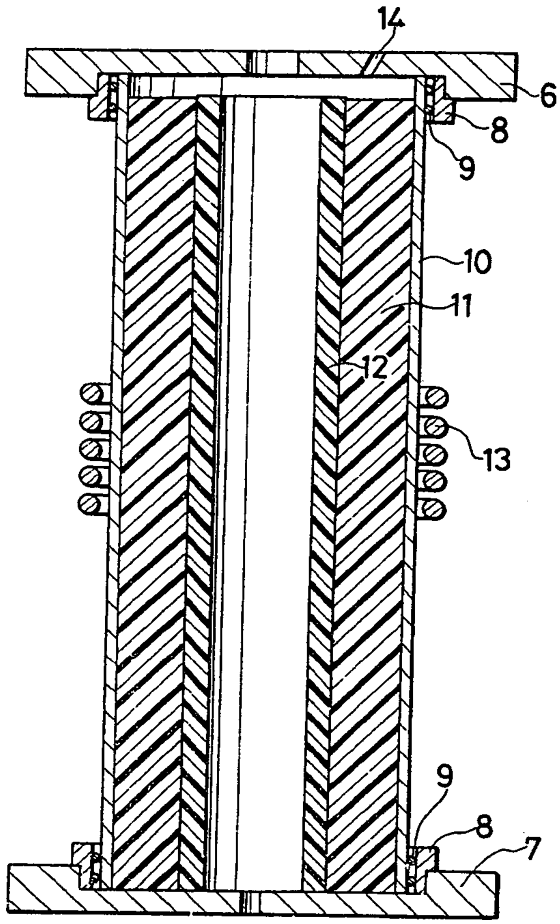

UPPER PORTION OF THE FUR-NACE
LOWER PORTION OF THE FURNACE
TEMPERATURE (°C)
2000
1900
1800
1700
1600
-6
-4
-2
0
2
4
6
AXIAL LENGTH OF THE FURNACE

FIG.3

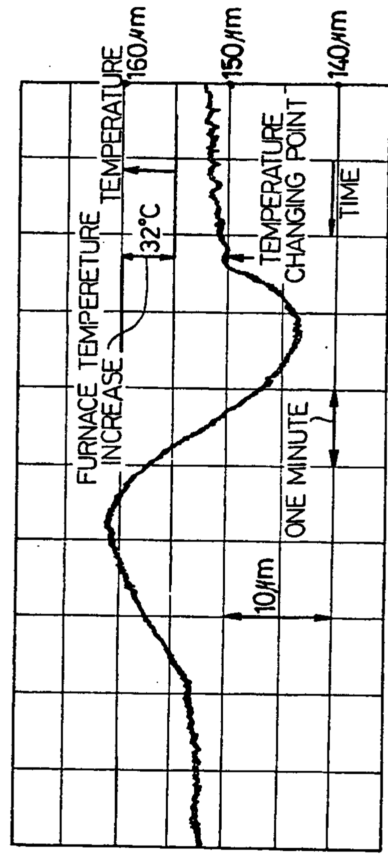


1575299 COMPLETE SPECIFICATION

11 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

FIG.4



OUTER DIAMETER VARIATION OF THE FIBER IN RESPONSE TO THE FURNACE TEMPERATURE CHANGE

FIG.6

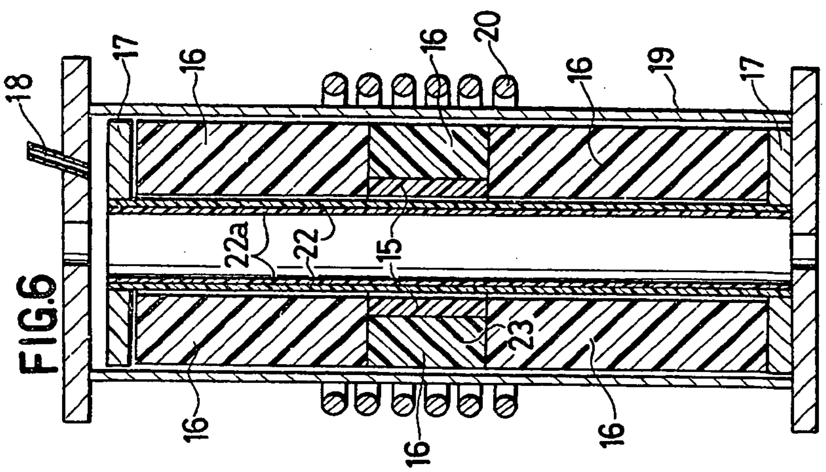

18
17
16
16
20
16
19
17
22a
22
15
23
16
16
16

FIG.5

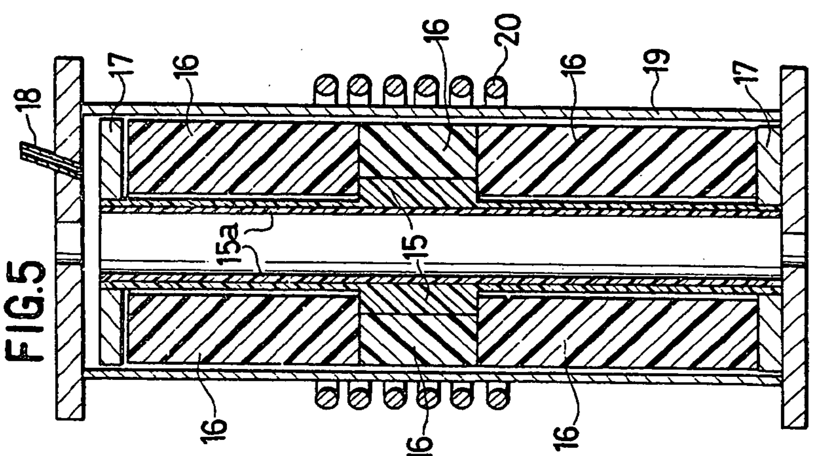

18
17
16
16
20
16
19
17
15a
15
16
16
16

FIG.7

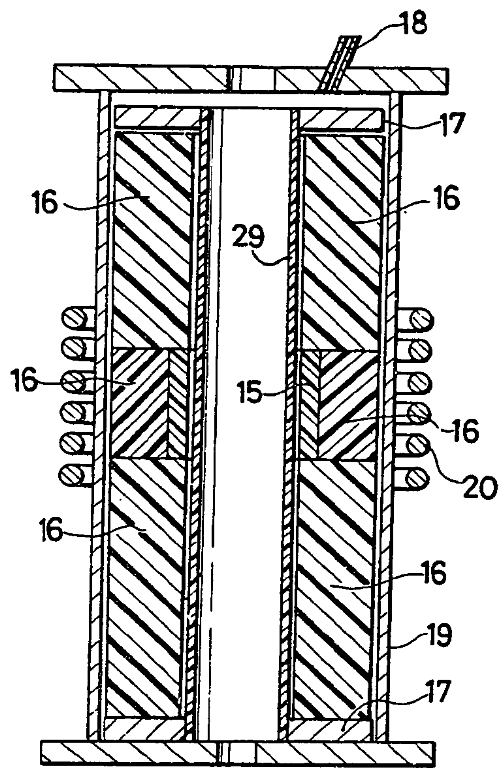
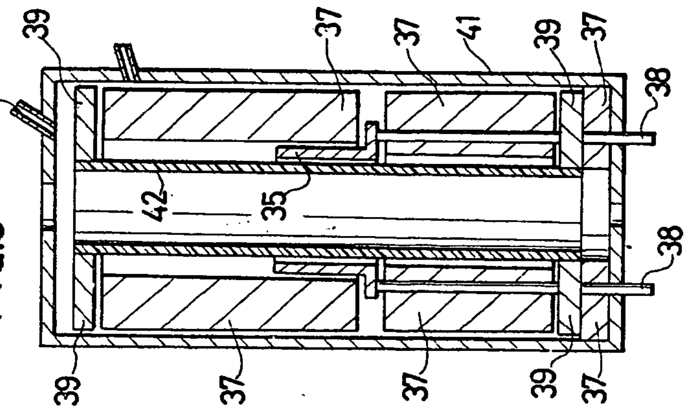


FIG.9


40
39
37
37
41
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37
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42
35
38
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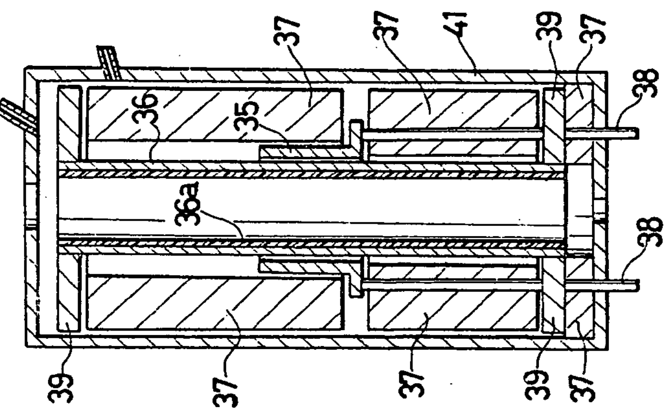
39
37

FIG.8


40
37
37
41
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37
38
36
35
36a
38
39
37
37
39
37

FIG.10

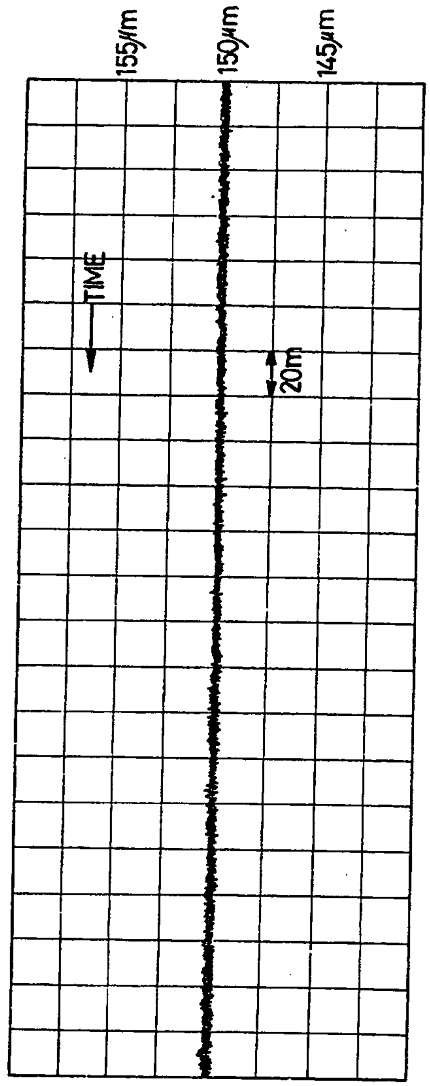


FIG.11

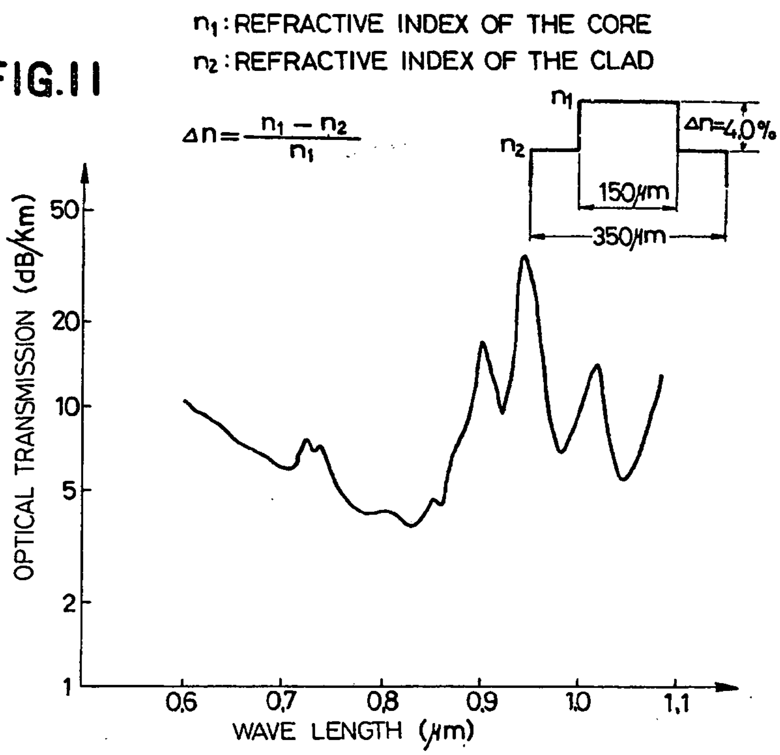

n_1: REFRACTIVE INDEX OF THE CORE
n_2: REFRACTIVE INDEX OF THE CLAD
$\Delta n = \frac{n_1 - n_2}{n_1}$
n_1
n_2
$\Delta n = 4.0\%$
150μm
350μm
OPTICAL TRANSMISSION (dB/km)
50
20
10
5
2
1
0,6
0,7
0,8
0,9
1,0
1,1
WAVE LENGTH (μm)

FIG.12

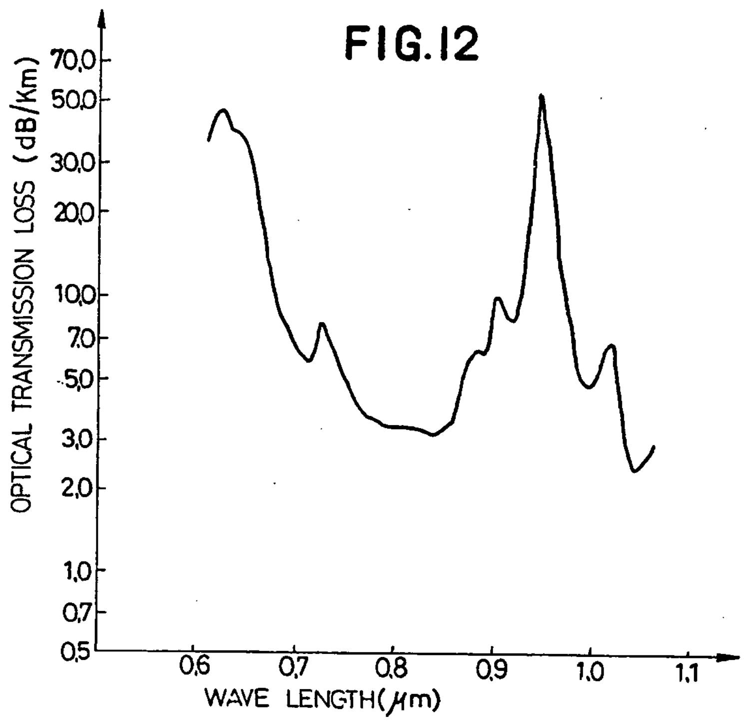

OPTICAL TRANSMISSION LOSS (dB/Km)
70,0
50,0
30,0
20,0
10,0
7,0
5,0
3,0
2,0
1,0
0,7
0,5
0,6
0,7
0,8
0,9
1,0
1,1
WAVE LENGTH(μm)

FIG.13

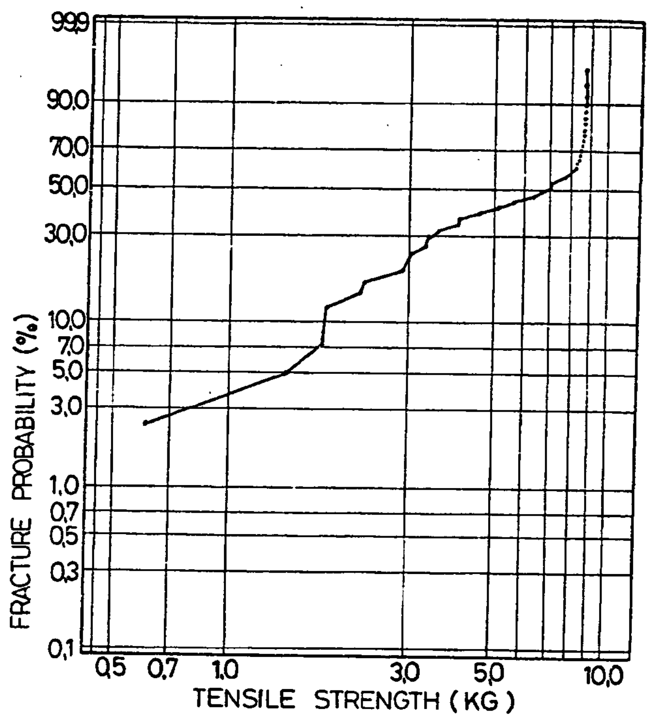
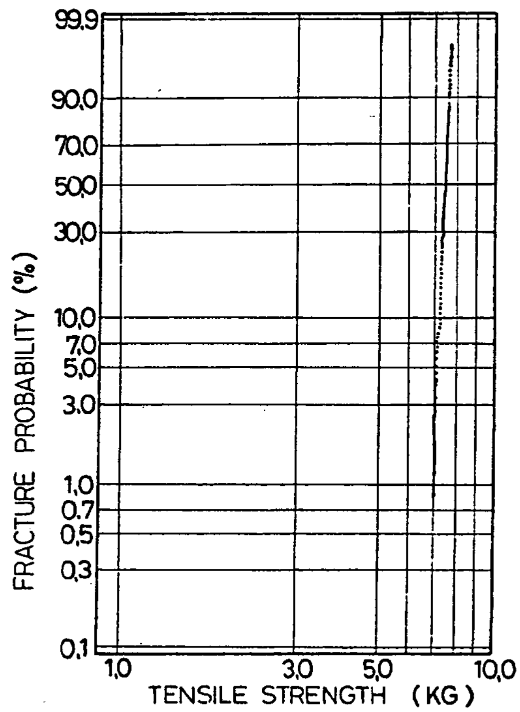

99.9
90.0
70.0
50.0
30.0
10.0
7.0
5.0
3.0
1.0
0.7
0.5
0.3
0.1
FRACTURE PROBABILITY (%)
0.5
0.7
1.0
3.0
5.0
10.0
TENSILE STRENGTH (KG)

FIG.14


99.9
90.0
70.0
50.0
30.0
10.0
7.0
5.0
3.0
1.0
0.7
0.5
0.3
0.1
FRACTURE PROBABILITY (%)
1.0
3.0
5.0
10.0
TENSILE STRENGTH (KG)